# AIR COMMAND AND STAFF COLLEGE

## STUDENT REPORT

KC-10 AIR REFUELING RENDEZVOUS WITHOUT ELECTRONIC EMISSION

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*"insights into tomorrow"*

REPORT NUMBER 88-1575

TITLE KC-10 AIR REFUELING RENDEZVOUS WITHOUT ELECTRONIC EMISSION

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Because radio transmissions and other electronic emissions are easily intercepted, they can provide clues to covert mission activity. To preclude compromise of those missions, aircrews may need to conduct air refueling rendezvous without electronic emissions. This study investigates factors related to this task. They are visual detection and identification, navigation capability, and timing control. Two traditional rendezvous flight paths and one new flight path are analyzed. The study concludes that visual rendezvous is possible. Further study is needed, however, to consider the effects of degraded visibility and the feasibility of a proposed new rendezvous procedure.

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# PREFACE

We have flown KC-10s throughout the world, have been involved in classified operations, and have supported short-notice taskings. In particular, we flew in support of United States actions against Libya and Grenada. It was common in our experiences to find those operations and taskings included procedures not previously established or published in our manuals. We, as KC-10 instructors and evaluators, understand the need for established procedures. The advantages of established procedures come from at least two areas. First, they can be developed and tested in a controlled manner rather than under intense time constraints and pressures. Second, established procedures can be learned and practiced by all aircrews in a calm, friendly environment rather than be tried for the first time in a hostile environment. Strategic Air Command has recognized the need for emission free air refueling rendezvous. This study is our attempt to contribute to the controlled process of developing procedures for use in a potentially hostile environment. We agree that we must train as we intend to fight.

# ABOUT THE AUTHOR

Major Michael W. Leuschen graduated from the Air Force Academy in 1975 with a Bachelor of Science degree in Astronautical Engineering. He completed UPT in October 1976. From UPT graduation until October 1981, he was assigned to the 92d Bomb Wing, Fairchild AFB, Washington, as a KC-135 copilot and aircraft commander. From October 1981 until August 1987, he was assigned to the 2d Bomb Wing, Barksdale AFB, Louisiana, as a KC-10 pilot and instructor. While there, he also served as the Chief of KC-10 Mission Development and the Chief of KC-10 Standardization and Evaluation. He was on temporary duty assignment to the United Kingdom during the United States strike against Libya in April 1986. Major Leuschen has a Master of Science degree in Systems Management from the University of Southern California. A 1981 graduate of Squadron Officer School, he attended Air Command and Staff College from August 1987 to June 1988.

Major Paul Williams graduated from the Air Force Academy in 1975 with a Bachelor of Science degree in Physics. In October 1975, he entered Undergraduate Pilot Training at Laughlin AFB, Texas. After graduation, he was assigned to the 380th Bomb Wing, Plattsburgh AFB, New York, as a KC-135 copilot and later aircraft commander. From November 1981 to August 1987, he was assigned to the 2d Bomb Wing, Barksdale AFB, Louisiana, as pilot, instructor pilot, Assistant Chief of Training Division, and Wing Standardization/Evaluation instructor pilot. He also served as the unit tactics officer. As such, he played a major role in the incorporation of the KC-10 into JCS and NATO plans and advised Headquarters Strategic Air Command (SAC) staff officers on the first KC-10 tactics manual. Major Williams has a Master of Business Administration degree from Rensselaer Polytechnic Institute, Troy, New York. A 1982 graduate of Squadron Officer School, he attended Air Command and Staff College from August 1987 to June 1988.

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**REPORT NUMBER** 88-1575

**AUTHOR(S)** MAJORS MICHAEL W. LEUSCHEN AND PAUL WILLIAMS, USAF

**TITLE** KC-10 AIR REFUELING RENDEZVOUS WITHOUT ELECTRONIC EMISSION

I. Purpose: To determine the capability of aircrews to conduct air refueling rendezvous, with a KC-10 tanker, without the use of radio and other electronic emissions.

II. Problem: To preserve the security of covert missions, air refueling rendezvous should be conducted without electronic emissions. With this restriction, aircrews would be unable to use the equipment upon which current rendezvous procedures are based. Aircrews could not use radios, radars, electronic beacons, or radio direction finding equipment. In addition, aircrews would not use navigation equipment such as TACAN and doppler radar. In effect, aircrews would navigate to a rendezvous point and join visually with another aircraft. Current capabilities must be understood. Procedures must be developed.

III. Data: Factors which affect the aircrew's ability to see a target aircraft are the target's apparent size, its proximity

to the aircrew's line of sight, and its contrast with the background. Aircraft apparent size is affected by its orientation to the observer. Greatest apparent size is achieved, in priority, by first exposing the top or bottom, then the sides, and lastly the front. Proximity to line of sight can be favorably influenced by having the target and the observer approach from known relative positions. Contrast has a significant impact on visual detection but cannot be standardized. It changes with each change in sky conditions. Basic research, field studies, and results from actual rendezvous suggest that under good daylight conditions aircrews could visually detect a KC-10 from 10 nautical miles away. Inertial navigation systems (INS) operate without electronic emissions and are the navigation system most commonly installed in aircraft. All SAC tankers have INS. The accuracy of current INS are generally adequate to allow rendezvous within the 10 nautical miles assumed necessary for visual detection and identification. Accuracy does, however, vary from system to system and changes over flight time. Aircrews have demonstrated ability to control timing enroute to a rendezvous point to arrive within a few seconds of the scheduled time. Current rendezvous procedures, point-parallel and enroute, can be adapted for use in emission out rendezvous. A modified procedure, which includes elements of both point-parallel and enroute procedures, offers advantages by enhancing target apparent size and time within the field of view.

IV. <u>Conclusions</u>: Current aircrew abilities and INS capabilities are adequate to conduct emission out rendezvous in good daylight conditions. As visibility conditions degrade, navigation errors and timing control become more critical. A rendezvous which uses a modified orbit offers advantages over current rendezvous methods.

V. <u>Recommendations</u>: Rendezvous without electronic emissions should be attempted under conditions of reduced visibility, in clouds, or at night without lights to determine actual limitations to the concept. The modified orbit described in this study should be flown to test for actual improvement over current methods. Aircrews should be taught visual search techniques to improve target detection.

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## Chapter One

## INTRODUCTION

> Surprise is the attack of an enemy at a time, place, and manner for which the enemy is neither prepared nor expecting an attack. The principle of surprise is achieved when an enemy is unable to react effectively to an attack. It is achieved through security, deception, audacity, originality, and timely execution. Surprise can decisively shift the balance of power (13:2-6).

In April 1986, the U.S. conducted a long range strike from the United Kingdom against targets in Libya. Air refueling of the F-111 strike aircraft was indispensable. Without multiple air refuelings, the F-111 aircraft would not have been able to complete the strike and return to their launch base. In order to preserve the security of the operation and the element of surprise, aspects of the operation were conducted without radio communication. Peacetime considerations, however, precluded complete radio silence.

On the morning after the attack, British newspaper stories included details of radio transmissions from the attack aircraft. British sources, the newspapers claimed, had intercepted those transmissions from the attacking force as it flew from British airspace. Radio transmissions are easily received even by non-hostile listening groups. Certainly radio and other electronic emissions could provide information to a hostile force intently searching for clues of attack operations.

In 1987, Strategic Air Command (SAC) changed its definition of the air refueling rendezvous to reflect options for control of emissions. SAC defined its most stringent option as "Emission Option 4 (Emission Out). No emissions (radios, Doppler, navigation transmitters, radar, IFF, exterior lighting, etc.) will be used unless specifically authorized by Air Tasking Orders (ATO), Rules of Engagement (ROE), Operations Plans, Safe Passage procedures, or other mission directives" (9:3-3). Less stringent options were also defined. Each of these less stringent options allowed electronic contact between airplanes so separation distances could be determined but, to varying degrees, restricted voice communication. These restrictions had little affect on the procedures normally used to conduct air refueling rendezvous. The emission out option, however, was a drastic

change to previously used procedures. In effect, aircrews attempting to rendezvous could make no electronic contact. Aircrews would have to visually find the other aircraft. This change in definition, however, offered no new procedures or techniques to accomplish the emission out rendezvous. In addition, when this definition was formally submitted for incorporation into the air refueling technical orders in the summer of 1987, it was accompanied by a restriction. "This option will not be practiced during peacetime operations unless specifically tasked by NAF or higher headquarters due to FAA identification requirements" (8:2).

The capability to accomplish an emission out rendezvous is one which must be developed and practiced to preserve the security of air refueling operations. A first step is to study the basic factors of the problem. This project identifies these factors as visual detection and identification, navigation capabilities, and timing control. Each of the next three chapters considers one of these basic factors. The final two chapters offer techniques to accomplish the rendezvous, identify some conclusions, and make recommendations for further investigation.

## Chapter Two

## VISUAL DETECTION AND IDENTIFICATION

> Aerial refueling should primarily support warfighting by increasing receiver aircraft endurance, increasing aircraft range, and permitting flexibility to respond quickly to any target location. Planners need to look at employment options that further enhance warfighting capabilities (6:33).

To employ the new concept of air refueling rendezvous without emission, aircrews must abandon the technical wizardry that has made the rendezvous almost a humdrum event. Aircrews must rely solely on their eyeballs to find and identify another aircraft. This chapter investigates some of the factors which affect this visual problem. It also reviews some basic research and field experiments to reach a general conclusion about the visual detection and identification problem.

Many studies have been made of human ability to see objects. One study, from the Virginia Polytechnic Institute, describes the problem. "The ability to detect an object by the unaided human eye is, fundamentally, a function of the apparent size of that object, its position within the field of view, the target's luminance, and the overall luminance of the scene" (17:12). This description identifies three major factors of the problem.

The first factor, the target's apparent size, is a function of the actual size of the object and its distance from the observer. The apparent size decreases as distance increases (5:237). The second factor, position within the field of view, is a measure of target position relative to the observer's line of sight. The further the target is from the line of sight, the more difficult it is to detect (17:34). The third factor, contrast, is influenced by both target luminance and background luminance. Contrast is a measure of difference between the target and its background. The target can be either darker or brighter than its background. It is, however, the magnitude of the difference between the target and the background that affects the target's visibility (17:14). Although there are other factors which affect the basic ability of the human eye to see an object, these three are most important and can be applied to the rendezvous problem.

With respect to a visual rendezvous, several observations can be made. First, the apparent size of the target aircraft, in addition to its distance, depends on its position relative to the observer. In his study of air-to-air visual acquisition, J.W. Andrews provides a method for computing the visual area of the target aircraft. Each aircraft has different visible areas, or profiles, when seen from the front (or rear), the side, or the top (or bottom) as shown in Figure 1. Sample profile areas, in square feet (sq ft), are shown in Table 1.

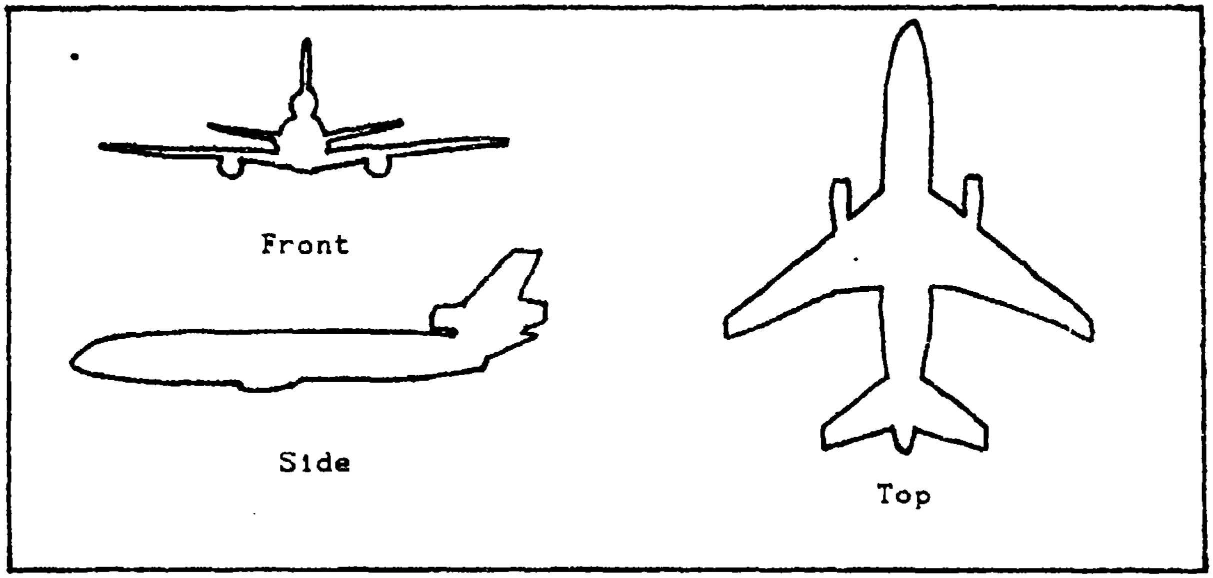


Figure 1. Profile Views (16:59)

| AIRCRAFT | FRONT - Ax | SIDE - Ay | TOP - Az |
|---|---|---|---|
| Fighter | 115 | 690 | 1270 |
| Boeing 727 | 330 | 1650 | 3100 |
| KC-10 | 900 | 4000 | 9000 |

Table 1. Approx. Profile Areas (sq ft)
(19:8; 16:60; 12:Fig 1.1-1)

Seen from an angle, portions of several profiles may be seen at once, but each will appear smaller than the full profile. The apparent area (Ax', Ay', Az') of each profile will then be equal to the full profile area multiplied by the cosine of the angle between the line of sight and a line normal to the profile. This is shown in Figure 2. Since some portions of the aircraft shield other portions, the whole visible area can be approximated by the area of the greatest apparent profile plus one-third of the other apparent profiles (16:60).

Visible area = max (Ax', Ay', Az') + 1/3 others

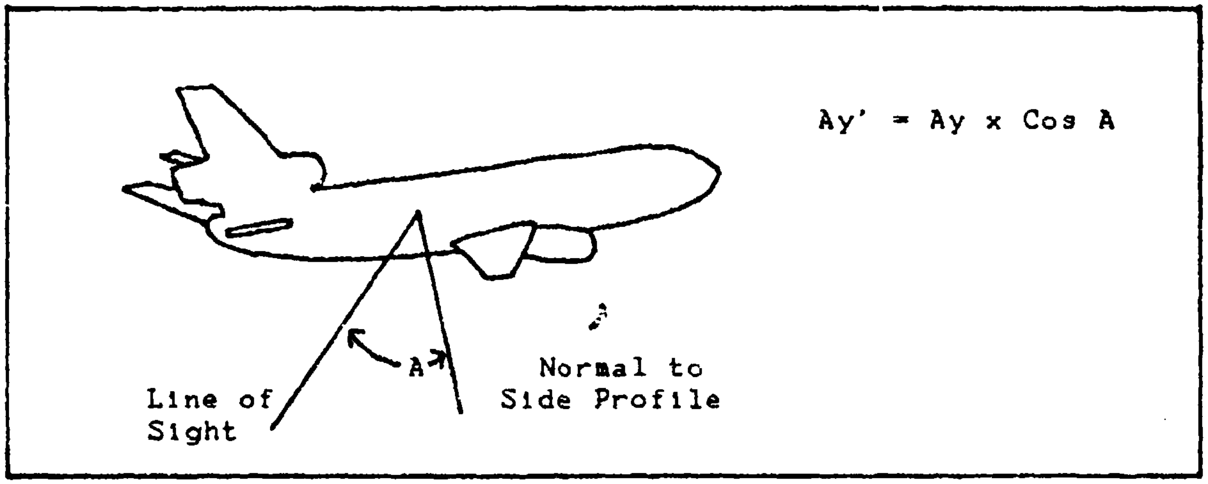


Figure 2. Apparent Profile Area

For example, given the approximate profile areas in Table 1 and a wings-level KC-10 seen from a position of equal altitude at a 45 degree angle, the visible area can be determined.

Ax' = Ax x Cos 45 = 900 x .71 = 640
Ay' = Ay x Cos 45 = 4000 x .71 = 2840
Az' = Az x Cos 90 = 9000 x 0 = 0

Visible Area = 2840 + 1/3 (640) = 3050 sq ft

Similar computations with the Boeing 727 and fighter aircraft result in visible areas of 1250 sq ft and 520 sq ft respectively.

Approaching the target aircraft from the top or bottom provides the observer the greatest visible area. However, since changing altitudes during a rendezvous would introduce undesired challenges to skill and safety, it seems appropriate to restrict

the aircraft to a designated altitude. Given the altitude restriction, more visible area is presented to an observer by the target's side profile or, if the target can maintain a bank, by the top or bottom.

The second visual factor, position within the field of view, must also be considered with regard to the rendezvous problem. Basic researchers have studied the probability of target detection when the observer was told the general position of the target. In this alerted condition, the observer was able to concentrate the search in a smaller portion of the sky. Compared to detection rates made without the alert, the alerted observers were able to increase detection rates by up to nine times (16:8). The lesson from this study is clear. The ability of aircrews to conduct a visual rendezvous should increase significantly if the aircraft are in visual range for long periods before the rendezvous point and if the aircrews know from which segment of the sky the target aircraft will approach.

The third visual factor, contrast, is one which cannot be quantified for the rendezvous. Because it depends on environmental conditions, relative position of the sun or moon, cloud conditions, color of aircraft, and much more, the actual contrast between aircraft and background will be different for each rendezvous. Results of target detection studies provide some general observations about aircraft-background contrast. First, the target is more readily visible against a background of sky than against one of ground. Secondly, the target is more readily visible against a background of slight haze than against a blue sky background (16:10). In addition, although data shows that with a known contrast a target becomes visible at a specified range, an observer must actually be much closer in order to feel confident that he has seen the target and will take action (5:249). The aircrews involved in the rendezvous must not only be confident they see the target aircraft, they must identify the aircraft as the proper one. From these studies and the use of nomographic charts, some estimates can be made of the distance at which an aircrew could see a target aircraft.

Nomographic charts can be used to predict the range at which a target becomes visible. These charts use standard luminance values for sky conditions. Then, given a contrast value, target area, and meteorological range, a distance can be found at which a circular target becomes visible (5:237-249). Using these charts, nominal values for contrast and meteorological range, and target areas as seen from a 45 degree angle, Table 2 shows approximate ranges in nautical miles (NM) at which the target (KC-10 or fighter) becomes visible.

| | KC-10 Target Range | | | | Fighter Target Range | | | |
|---|---|---|---|---|---|---|---|---|
| Met range | 15 NM | | 5 NM | | 15 NM | | 5 NM | |
| Contrast | 1.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 |
| Day | 14.0 | 11.0 | 4.0 | 3.5 | 10.0 | 8.0 | 3.4 | 2.9 |
| Twilight | 11.5 | 9.5 | 3.8 | 3.0 | 6.5 | 5.5 | 2.8 | 2.4 |
| Moonlight | 5.5 | 4.3 | 2.3 | 1.8 | 3.3 | 2.5 | 1.6 | 1.3 |
| Starlight | 1.5 | 1.0 | 0.9 | 0.6 | 0.8 | 0.5 | 0.5 | 0.4 |

Table 2. Approximate Range (NM) for Target Detection (5:Fig 2,5,7,9)

In addition to the values derived from the nomographic charts, field studies also help approximate the ranges at which aircraft could be detected. Although aircraft type and visibility conditions are not identified in all these studies, one study showed that relatively small aircraft were visually detected by 80% of the observers when the target got within 2.7 NM (4:288). How does this compare to results obtained during actual rendezvous?

In an attempt to compare the basic research data to the rendezvous problem, aircrews were asked to report ranges at which they saw and identified the other aircraft during normal, emission assisted, air refueling rendezvous. Individual results are shown in Appendix 1. When KC-10 and KC-135 aircraft (SAC tankers) were the targets in good daylight conditions, aircrews detected about 53% of the targets at a range of 7 - 11 NM. The rest were first seen at ranges greater than 11 NM. Aircrews reported target identification at ranges of 6 NM or less in about 67% of the rendezvous and at ranges of 10 NM or less in nearly all cases. Ranges for other types of targets and in other weather and lighting conditions varied. In one instance, a pilot reported seeing another aircraft which could have been mistaken for the target (25:--). The authors recall other reports of mistaken identity during normal rendezvous attempts. Because the observations were not made under uniform conditions, and contrast and meteorological range were not measured, these results cannot challenge or confirm other studies. They do, however, provide the basis for an estimate of the distance at which aircrews can detect and identify tanker aircraft.

Basic research has provided a framework in which to investigate visual detection and identification during rendezvous. Target size, position, time, and environmental conditions are all important factors. This basic research,

coupled with actual rendezvous experience, provides some general boundaries to the visual rendezvous problem. If a receiver aircraft, in good daytime visibility, is within 10 NM of a KC-10, then the receiver crew should be able to see the KC-10. With that premise, the rendezvous problem becomes one of aircraft capabilities, aircrew abilities, and procedures. Are the aircraft navigation systems and aircrew abilities sufficient under emission out conditions to bring the aircraft within sighting distance? The next chapter investigates navigation capabilities and relates those capabilities to the emission out rendezvous problem.

## Chapter Three

## NAVIGATION CAPABILITIES

> The technique of interception was as follows. The receiver's flight plan was signalled to the tanker's base prior to take-off, after which position reports were sent from the receiver stating E.T.A., fuel required and point of rendezvous. W/T communication between the two aircraft was established at a separation of about 300 miles, and later V.H.F. communication when 70 to 100 miles apart, radar interception being made about the same time (1:15). (1947 British air refueling trials)

In the past, at least since 1947, aircrews have used radar as well as radio communication to conduct air refueling. During an emission out rendezvous, aircrews could not use those tools. Instead, they would rendezvous by arriving over the same geographic point or closely enough to permit visual detection. The ability of an aircrew to fly an aircraft to a rendezvous point is largely dependent on the navigation systems of the aircraft, the accuracy of those navigation systems, and the aircrew's ability to use those systems. This chapter reviews the accuracy of emission-free inertial navigation systems and considers navigation errors with regard to the rendezvous problem. The resulting situation is then compared with the visual detection capability discussed in the previous chapter. First, a look at navigation system accuracies.

Typical navigation systems include terrain mapping radar, TACAN and other ground based radio aids to navigation, celestial navigation, doppler navigation systems (DNS), and inertial navigation systems (INS). Navigation by visual reference to the ground is sometimes used but, because the air refueling rendezvous may be accomplished above cloud layers or over water, this method will not be considered. Of the remaining methods, only celestial navigation and inertial navigation systems are free of electronic emission. Few types of aircraft have celestial navigation systems. Therefore, assuming the prohibition of electronic emission, the KC-10 and most other military aircraft would be forced to rely solely on inertial navigation systems to find the rendezvous point. How accurate are these systems?

KC-10s use three Litton INS for navigation. After each flight, aircrews check the accuracy of each INS to determine the errors induced during flight. Table 3 shows the post-flight error per flight hour for a random selection of 5 aircraft over a total of 70 flights. Eighty-five percent of the INS operations resulted in an error rate of .75 NM/HR or less. Sixty-five percent of the INS operations resulted in an error rate of .50 NM/HR or less. These results were achieved through independent INS operation (20:--).

| | | | | |
|---|---|---|---|---|
| Error Rate | 0 - .25 | .25 - .50 | .50 - .75 | .75 - 1.00 |
| # of INS | 91 | 47 | 42 | 20 |
| Percentage | 43 | 22 | 20 | 10 |
| Error Rate | 1.00 - 1.25 | 1.25 - 1.50 | 1.50 - 1.75 | 1.75 or more |
| # of INS | 5 | 2 | 2 | 1 |
| Percentage | 2 | 1 | 1 | 0.5 |

Table 3. INS Error Rate (NM/HR) (20:--)

The KC-10 navigation system also has the capability to combine individual INS computations in flight. In this mode, the system uses position information from each INS and determines a single position, called a triple mix position. The system presents this position to the aircrew for navigation. While preparing for SAC's Bombing and Navigation Competition in 1986, the KC-10 project officer at Barksdale AFB collected and studied the post-flight accuracy of this triple-mix position. A random selection of data for 20 aircraft shows the error rate for the individual INS and for the triple mix position as condensed in Table 4. The triple mix computation improves the chances of smaller error rate during normal operations.

Investigation of the accuracy of INS on other aircraft revealed that their basic INS performs with similar accuracy. Instructor pilots at MacDill AFB and Altus AFB, training bases for F-16, C-5, and C-141 crews, report results of equal or better accuracy and reliability (24:--; 23:--; 22:--). KC-135 INS maintenance personnel at Barksdale AFB also report equal or better accuracy and reliability (21:--). Given these INS accuracies, these general error rates, and the fact that the absolute error between computed and actual position changes over time, how do the navigation capabilities impact the visual rendezvous problem?

| | 0-.25 | .25-.50 | .50-.75 | .75-1.00 | 1.00 or more |
|---|---|---|---|---|---|
| (%) | | | | | |
| Individual | 12 | 30 | 32 | 18 | 8 |
| Triple Mix | 20 | 45 | 30 | 5 | 0 |

Table 4. Triple Mix INS Error Rate (NM/HR) (18:--)

To successfully rendezvous, at least one aircrew must be in a position to see the other aircraft. Figure 3 shows the aircraft at the rendezvous time. Each aircrew uses its navigation system to arrive at the rendezvous point. But, because the navigation system has developed an error, the aircraft will not be exactly at the point. If the tanker arrives with a navigation system error of T NM, when the system says it is at the rendezvous point it could be anywhere T NM away from the actual point. If the receiver arrives with a navigation system error R NM, it could be anywhere R NM from the rendezvous point. In combination, with errors at their relative worst, the aircraft arrive at the rendezvous T + R NM apart.

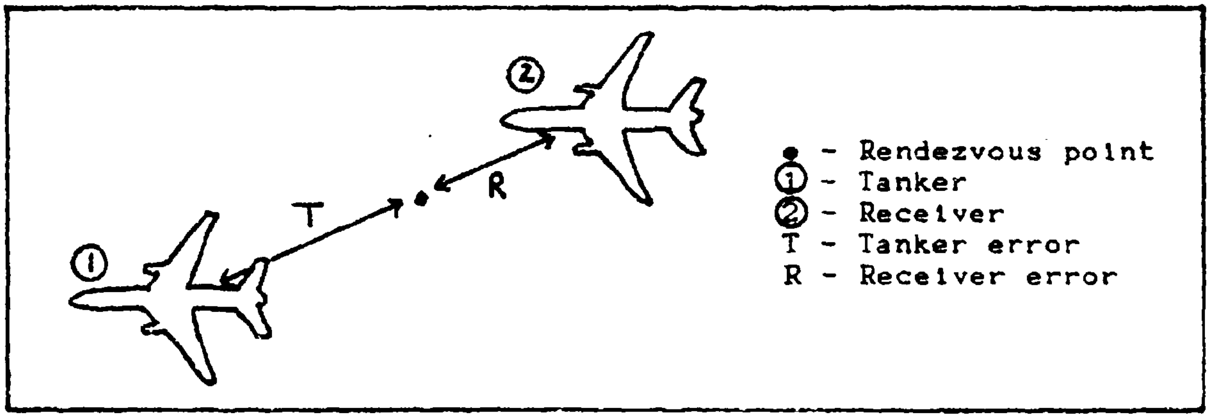


Figure 3. Navigation Error at Rendezvous

At the rendezvous time, for one aircrew to see the other's aircraft, the visual detection range must be greater than the distance between the aircraft. Depending on relative positions and visual detection ranges, it is possible that both, one, or neither of the aircraft will be seen by the other's crew. For

example, after a 5-hour flight, assume the KC-10 tanker has a navigation error of 1.5 NM and a single F-16 receiver has an error of 2.0 NM. At most, the two aircraft would be 3.5 NM apart. From the general values in Table 2, page 7, for day conditions, a contrast of 0.5, and 15 NM meteorological range, the KC-10 would be visible at 11 NM and the F-16 would be visible at 8 NM. Either aircrew should be able to see the other's aircraft. If this situation existed in moonlight, Table 2 shows the KC-10 and the F-16 would be visible at 4.3 NM and 2.5 NM respectively. From positions 3.5 NM apart, only the KC-10 would be within visual detection range. The F-16 would be beyond detection range.

An analysis of visual information and navigation accuracies can answer two important questions. Given the visual conditions under which the rendezvous is conducted, are the navigation system accuracies sufficient? Or conversely, given the accuracies of the navigation systems, how much can visual conditions deteriorate and still be good enough for the emission out rendezvous? From the discussion in Chapter One, it seems that navigation accuracy is sufficient for rendezvous in good weather in daylight. Its sufficiency for rendezvous in degraded conditions depends on the conditions themselves. Analysis in this chapter, relating navigation capabilities to visual detection, has assumed that both aircraft arrive at the designated rendezvous point at the planned rendezvous time. The next chapter will discuss the impact of changes in this assumption on the rendezvous.

## Chapter Four

## IMPACT OF TIMING ERROR

Closely related to navigation error on rendezvous success is the effect of timing error. However, the difference between navigation errors and timing errors is significant enough to justify an isolated discussion of timing errors. The SAC Bombing and Navigation Competition, for instance, grades position error and time deviation separately in those exercises which measure navigation accuracy (7:VII-1, VIII-1). This chapter will investigate the affect of timing errors on the success of an emission out rendezvous. It will explain the difference between timing and navigation errors, discuss some of the factors affecting timing accuracy, investigate the current lack of concern for timing accuracy, show the effects, mathematically, of timing errors, and look at the current capability of flight crews to accurately time a mission event.

Navigation and timing pose two separate problems to the flight crew and require two separate solutions. The solution to the navigation problem is "where." The solution to the timing problem is "when." An example should clarify this difference and demonstrate timing's significance. In World War II, one of the most costly (in terms of allied aircraft lost) bombing raids was the Schweinfurt-Regensburg mission. The mission was originally timed so that the Schweinfurt bombers and Regensburg bombers would enter enemy airspace together, both benefitting from their combined fighter escorts and sharing the brunt of German fighter attacks. Due to poor weather in England a decision was made to delay the Schweinfurt bombers. The result was disastrous. "The [timing] interval chosen was to prove the worst possible solution. Both bomber forces were denied the opportunity to have the fullest available fighter support, while the German fighter units would easily be able to fly sorties against both penetrations" (2:76-79). Both groups navigated accurately through the enemy defenses, but the effect of the changed timing directly contributed to the tragic outcome of the mission.

In the example above, the timing "error" was committed in the planning, not the execution, of the mission. Other errors can have a more obvious impact on mission timing. These errors can be classed as unknown and known. Unknown errors are introduced

into the mission without the crew's knowledge. Staff planners can schedule the rendezvous time in error. Mission planners can make computational errors on the flight plan. Crews can misinterpret flight plans or simply misread (or misset) the clock. The danger to mission success is that, without knowledge of the error, the crew will not attempt to correct it. Known errors are those that affect mission timing which occur with the crew's knowledge. An early or late takeoff, for any number of reasons, will affect mission timing. Route changes, due to weather or mission requirements, will also have an affect. Finally, an unanticipated groundspeed will affect mission timing. Depending on the mission profile and the initial error, the crew may have considerable means to correct the error such as airspeed or route changes.

Another factor which impacts the crew's timing accuracy is the current lack of concern for minimizing timing errors. There are two reasons for this. The first is the dependence on other means for accomplishing the rendezvous. Technical Order 1-1C-1-33, KC-10 Flight Crew Air Refueling Procedures, states:

> The tanker will utilize the inertial navigation system (INS) combined with the TACAN in beacon inverse mode as the primary [rendezvous] means. Alternate procedures will include the combined use of all equipment aboard the airplane that can be used to effect a rendezvous. Such equipment includes the radar/beacon, UHF/ADF radio, common ground TACAN/VORTAC stations, FAA GCI facilities, and timing (11:2-5).

Timing is listed as the last alternate procedure. And although crews practice using timing, the training is conducted with the primary equipment still on. Thus, the crews go through the motions of using timing as an alternate rendezvous procedure, but never truly rely on it to accomplish the rendezvous. The second reason for the lack of concern for timing comes from the type of rendezvous most commonly used. The point parallel rendezvous (to be discussed in detail in the next chapter) relies on the crew's computing a distance, the turn range, between tanker and the receiver which will allow the tanker to turn in front of the receiver. Once the rendezvous is initiated, the emphasis is on the distance between the two aircraft. The time at which the rendezvous is completed becomes virtually irrelevant.

Without the use of signal emitting rendezvous equipment, the distance between the two aircraft remains an unknown. The rendezvous problem changes from one of decreasing the distance between aircraft to zero to one of navigating two aircraft to the same geographic position at the same time. Timing now becomes critical. Chapter Three examined the affects of pure navigation error on the rendezvous problem. In order to examine the effect

of timing error, that error must somehow be converted to a distance and the distance error compared to the visual detection criteria described in Chapter Two. The distance error caused as a result of a timing error is dependent on the speed of the aircraft. The following table shows a conversion of timing errors to distance errors for various speed.

TIMING ERROR/DISTANCE ERROR

| | | (Seconds) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15.0 | 30.0 | 45.0 | 60.0 | 75.0 | 90.0 | 105.0 | 120.0 | 135.0 | 150.0 | 165.0 | 180.0 |
| | 400 | 1.7 | 3.3 | 5.0 | 6.7 | 8.3 | 10.0 | 11.7 | 13.3 | 15.0 | 16.7 | 18.3 | 20.0 |
| | 450 | 1.9 | 3.8 | 5.6 | 7.5 | 9.4 | 11.2 | 13.1 | 15.0 | 16.9 | 18.8 | 20.6 | 22.5 |
| | 500 | 2.1 | 4.2 | 6.2 | 8.3 | 10.4 | 12.5 | 14.6 | 16.7 | 18.8 | 20.8 | 22.9 | 25.0 |
| | - | - | - | - | - | - | - | - | - | - | - | - | - |
| (TAS) | 800 | 3.3 | 6.7 | 10.0 | 13.3 | 16.7 | 20.0 | 23.3 | 26.7 | 30.0 | 33.3 | 36.7 | 40.0 |
| | 850 | 3.5 | 7.1 | 10.6 | 14.2 | 17.7 | 21.2 | 24.8 | 28.3 | 31.9 | 35.4 | 39.0 | 42.5 |
| | 900 | 3.8 | 7.5 | 11.2 | 15.0 | 18.8 | 22.5 | 26.2 | 30.0 | 33.8 | 37.5 | 41.2 | 45.0 |
| | 950 | 4.0 | 7.9 | 11.9 | 15.8 | 19.8 | 23.8 | 27.7 | 31.7 | 35.6 | 39.6 | 43.5 | 47.5 |
| | 1000 | 4.2 | 8.3 | 12.5 | 16.7 | 20.8 | 25.0 | 29.2 | 33.3 | 37.5 | 41.7 | 45.8 | 50.0 |

Table 5. Distance Error (NM)

The information from this table can be considered in two ways. The top half considers the effect of timing on a single aircraft (or two aircraft coming from roughly the same direction). The bottom half, the effect on two aircraft coming from roughly the opposite directions. In the first case, the table shows the effect of timing errors from 15 seconds to 180 seconds for aircraft with airspeeds ranging from 400 knots to 500 knots, normal rendezvous airspeeds. The error ranges from less than 2 miles to 25 miles. In the worst case, the combined effect of two aircraft coming from opposite directions, the distance error results from the sum of the two aircraft airspeeds, 800 knots to 1000 knots. The error here ranges from over 3 miles to 50 miles. With this information, the timing accuracy that crews are currently capable of maintaining can be investigated.

As previously mentioned, crews normally do not use timing as the primary means for accomplishing rendezvous. Therefore, little information can be gained from normal air refueling training missions about crews' abilities to accurately time. One

source of information is available. It is the SAC Bombing and Navigation Competition. Because timing accuracy is scored separately from position accuracy in the navigation portion of this competition, crews must consider, and therefore attempt to minimize, timing errors. Crews compete in a variety of navigation exercises varying primarily in the type of equipment authorized. For example, the KC-135 compete using radar navigation, day and night celestial navigation, and INS navigation. For this investigation, the KC-135 night celestial navigation, KC-135 INS navigation, and the KC-10 INS navigation results will be reviewed. These results are appropriate because they were attained without the use of any emitting navigation equipment. Tables 6, 7, and 8 depict the average timing errors for KC-135 from 1981 to 1986 and KC-10 aircraft from 1982 to 1986.

The average timing error for KC-135 celestial navigation over the period was 25 seconds. The average for the KC-135 INS navigation was 10 seconds. At a 450 knot rendezvous speed this equates to 3.2 nautical mile and 1.3 nautical mile distance errors respectively. The average timing error for KC-10 INS navigation was 4 seconds. At 450 knots this equates to a 0.5 nautical mile distance error.

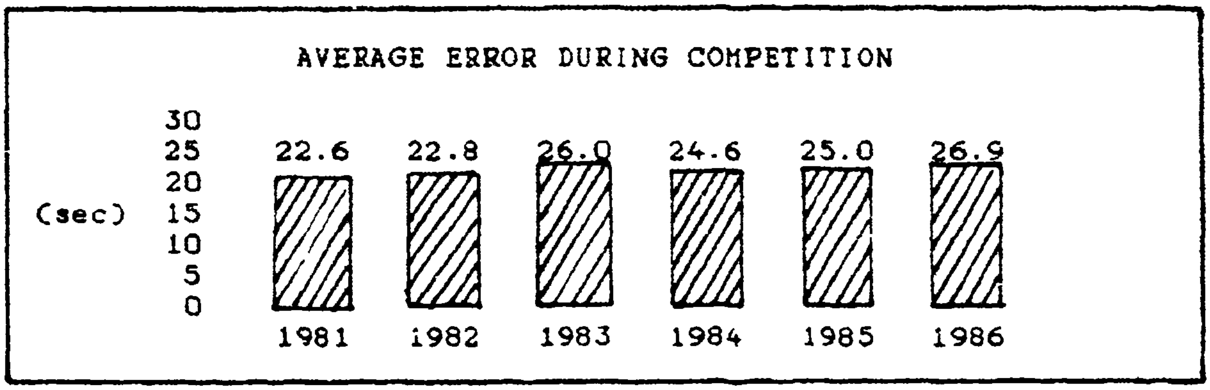


Table 6. KC-135 Celestial Navigation Timing Errors (7:VII-9)

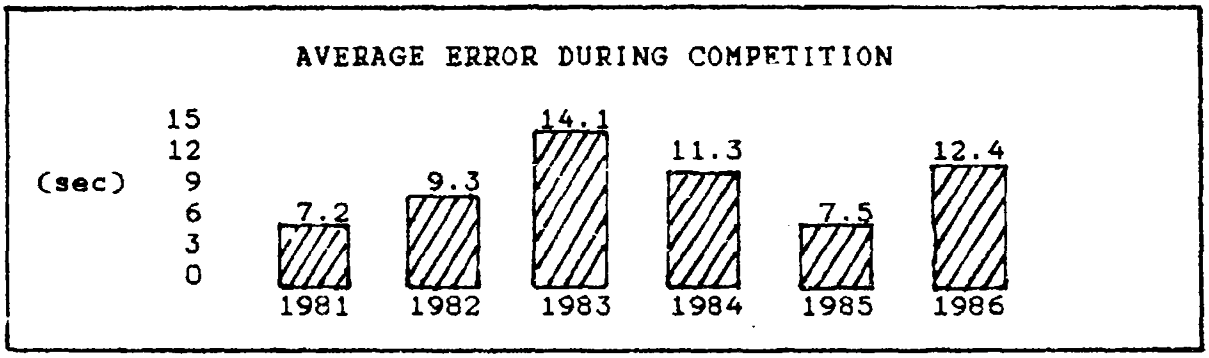


Table 7. KC-135 INS Timing Errors (7:VII-11)

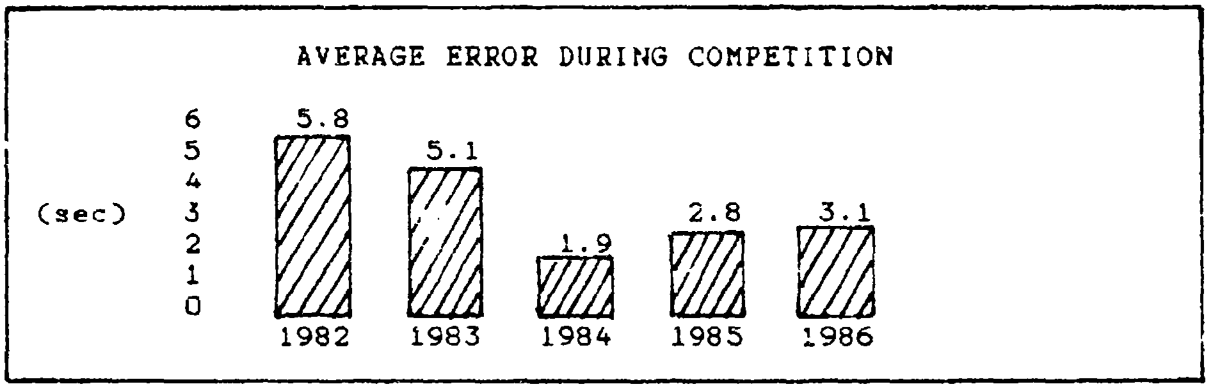


Table 8. KC-10 INS Timing Errors (7:VIII-2)

The impact of timing errors on rendezvous success can be significant. For example, Table 5 shows that a 60 second timing error by two rendezvousing aircraft closing at 850 knots will result in a distance error of over 14 NM. This exceeds the typical 10 NM visual detection range from Chapter Two. The capabilities of the equipment and crews are, however, more than adequate to minimize the effect of timing errors. The results of the SAC Bombing and Navigation Competition are evidence that it is possible to limit timing errors to 10 seconds (the KC-135 average INS timing error) or less. Even with these demonstrated errors, the aircraft would be well within the visual detection tolerances.

Current procedures which define signal-emitting eq as primary aids in performing rendezvous have taught tanke

receiver crews to de-emphasize the clock. Emission out procedures will take that equipment away. If crews and planners recognize the importance of timing for the emission out rendezvous, begin to practice its use, and develop confidence in this new procedure, this chapter has shown that a rendezvous can be successfully completed using timing as the primary rendezvous aid.

The next chapter will examine various rendezvous procedures to determine which ones are most suitable and offer the greatest chance of success for emission out rendezvous.

## Chapter Five

## RENDEZVOUS PROCEDURES

Previous chapters discussed the criteria for evaluating the probable success of a rendezvous without using electronic means. Simply put, if the rendezvousing aircraft can navigate and time accurately enough to be within visual range of one another at the completion of the rendezvous, then a successful rendezvous is possible. This chapter will investigate three rendezvous procedures to consider their suitability for emission out rendezvous. The three procedures are the point-parallel, the enroute, and a modified point-parallel procedure.

Of the three criteria considered, visual detection, navigation, and timing error, only one is affected by the type of rendezvous. Navigation and timing are functions of aircraft system and crew capabilities. There is no evidence to indicate that a particular rendezvous can improve or degrade the navigation or timing of aircraft or crews. Different rendezvous procedures will, however, impact the visual detection criteria. Specifically, different rendezvous will place the aircraft within visual detection range for different lengths of time and present different apparent target sizes. These two sub-criteria will be the basis for examination of the three rendezvous.

For each of the rendezvous procedures to be examined, various factors such as size of the tanker and receiver aircraft, tanker and receiver airspeed, winds, and turning rates, will affect the computations and, therefore, the results. Since the purpose of these examinations is not to discover the possible range of outcomes, but rather to compare the various rendezvous procedures with each other, only one set of computations per example will be given. The factors selected are considered typical based on the experiences of the authors. When appropriate, conditions will remain constant throughout the examples. For all the examples the tanker will be a KC-10 and the receiver will be the same size or smaller than a KC-10.

One factor, airspeed, does deserve specific attention because it can vary significantly from rendezvous to rendezvous. Tankers in an orbit can adjust orbit leg length to adjust timing to the Air Refueling Control Time (ARCT), but tankers using enroute rendezvous procedures, and all receivers, must consider airspeed

adjusting as a primary means to adjust timing. To show the effect of airspeed adjustment for each type of rendezvous procedure, the effect of a 100 knot increase in airspeed by the receiver will be computed.

## POINT PARALLEL RENDEZVOUS

The first rendezvous to be examined is the point parallel rendezvous. Using this procedure with electronic emitters active, the tanker orbits at the Air Refueling Control Point (ARCP) until the receiver crosses the Air Refueling Initial Point (ARIP) flying toward the ARCP. The Air Refueling Control Time (ARCT) is used for planning the rendezvous, but the rendezvous is completed using the turn range (TR), the distance between the aircraft, to determine the start of tanker's rendezvous turn (11:2-6 - 2-10). Two minor modifications will be made to the standard procedure to permit the rendezvous to be accomplished without electronic means and to improve the probability of visual detection. First, because the normal point parallel rendezvous relies on aircraft-to-aircraft distance determined by electronic means, it cannot be used in an emission out environment without modification. The modification necessary is the replacement of the standard tanker orbit with a timed orbit very similar to the one currently used during SR-71 rendezvous (11:7-54 - 7-59). A timed orbit allows the tanker to plan an orbit pattern to arrive over the ARCP at exactly the ARCT. The second modification changes the distance between aircraft at the end of the rendezvous. Normally, the tanker will complete its rendezvous turn 3 nautical miles in front of the receiver. This spacing allows the receiver to make a controlled closure on the tanker. In an emission out environment, the necessity for minimizing the distance between aircraft to maximize the possibility of visual contact overrides this luxury. In this examination, the procedure will be planned so the two aircraft arrive at the ARCP at exactly the same time and there is no planned distance between the aircraft at the end of the rendezvous.

Figure 4 shows the relationship of the two aircraft at the start of the tanker's rendezvous turn. The offset (OS), the width of the orbit, and the turn range (TR), the distance between the aircraft at the start of the tanker rendezvous turn, are computed based on the speeds of the aircraft and the effect of wind drift. In a normal rendezvous, the tanker requires electronic means to determine when it has reached the turn range. In an emission out rendezvous the distances must be the same, but must be determined using the timed orbit.

Figure 4 also shows the relationship of the two aircraft as the rendezvous progresses. As the tanker completes its

rendezvous turn, the receiver flies along its track to the ARCP, closing the distance between the aircraft.

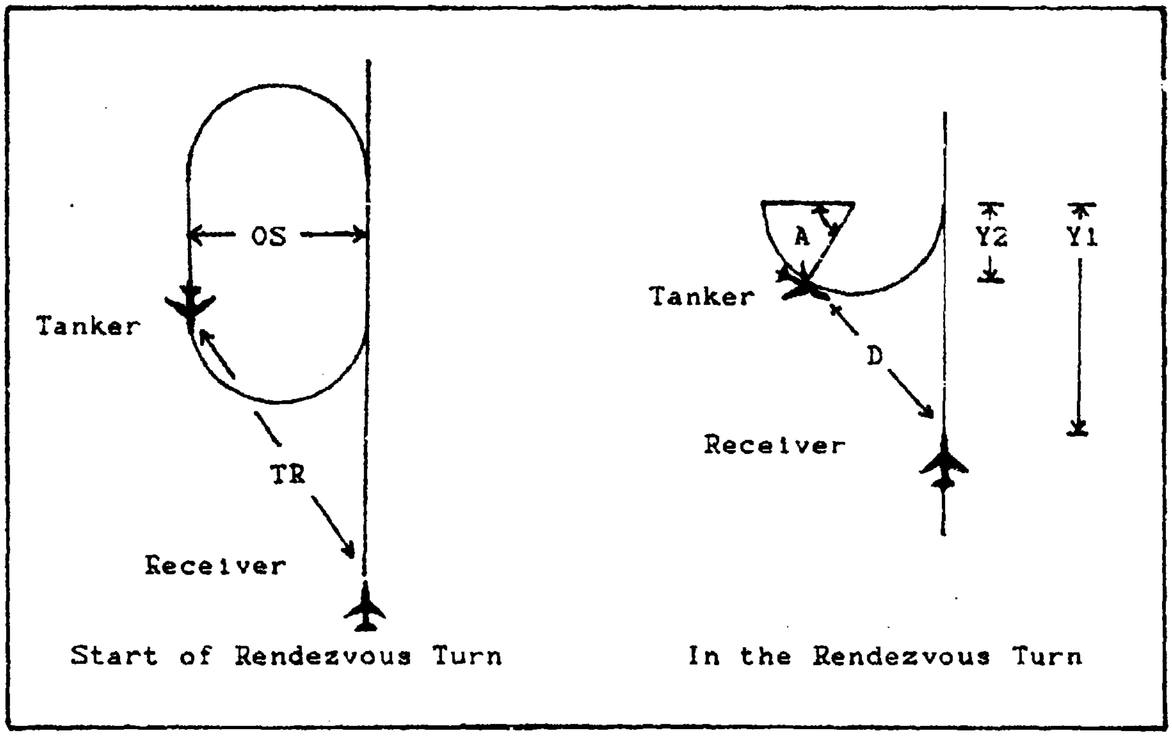


Figure 4. Point Parallel Rendezvous

The equation which determines the distance, D, between the two aircraft is

D = SQR [ OS/2 + OS/2 x (Cos A)^2 + (Y1-Y2)^2 ]

where

OS = offset = tanker turn diameter
A = angle subtended in tanker turn
Y1 = distance from receiver to ARCP
Y2 = distance along track from tanker to ARCP
^ = symbol indicating exponential.

The equation which determines the angle subtended by the tanker is

$$A = 1.2 \times T$$

where

$$T = \text{time (sec)}.$$

The following variables were selected for this examination:

Tanker true airspeed = 400 kts
Receiver true airspeed = 450 kts
Wind = no wind
Tanker bank angle = 25 degrees
Tanker turn rate = 1.2 degree/sec (14:133)
Tanker turn diameter = 10 NM (14:133).

A short, iterative program was used to solve both equations simultaneously. With D set equal to 10 NM, a typical visual range determined in Chapter Two, the solution was 94 seconds. This means that the tanker and receiver should be within 10 NM of each other for the last 94 seconds of the rendezvous or for 94 seconds prior to the ARCT. If the receiver's airspeed is increased by 100 knots, due to aircraft procedures or timing considerations, the time in the visual range drops to 84 seconds. A detailed mathematical computation and a listing of the program are in Appendix 2.

The second consideration for this type of rendezvous is the apparent target size. From the discussion in Chapter Two, the apparent size of a target is a function of its actual size, its distance from the observer, and its position relative to the observer. If the size and distance are held constant, some calculations can be made based on relative position. Since the relative position is a function of the type of rendezvous, some general insight into the effect of the different types of rendezvous on apparent target sizes can be made.

The technique from Chapter Two to quantify the effect of relative position is to compute the visible area of the target. The equation which gives an approximation of the visible area is:

$$\text{Visible area} = \max(Ax', Ay', Az') + 1/3 \text{ others}.$$

The relative position of the two aircraft the first time they are within the 10 NM range is shown in Figure 5. The angles in the figure and the computations of Ax', Ay', and Az' below show the relationship of the viewer to the full profile (front, side, and bottom) of the target.

Because of the different relative positions of the tanker and the receiver, the aircraft have different visible areas. In this rendezvous, the tanker has the greater visible area.

(Front) $A_x' = A_x \times \cos 23 = 900 \times .92 = 828$
(Side) $A_y' = A_y \times \cos 67 = 4000 \times .39 = 1560$
(Bottom) $A_z' = A_z \times \cos 64 = 9000 \times .44 = 3960$

Visible area = 3780 + 1/3 (828 + 1560) = 4756 sq ft

As the rendezvous continues, the visible area of the tanker changes as its relative position changes. An examination of this change, though mathematically possible, is beyond the scope of this paper. It is also intuitively obvious that, as the rendezvous continues, the visible area becomes less significant as the aircraft get closer. This initial visible area, approximately 4800 sq ft, however, can be used in comparison with the other rendezvous procedures.

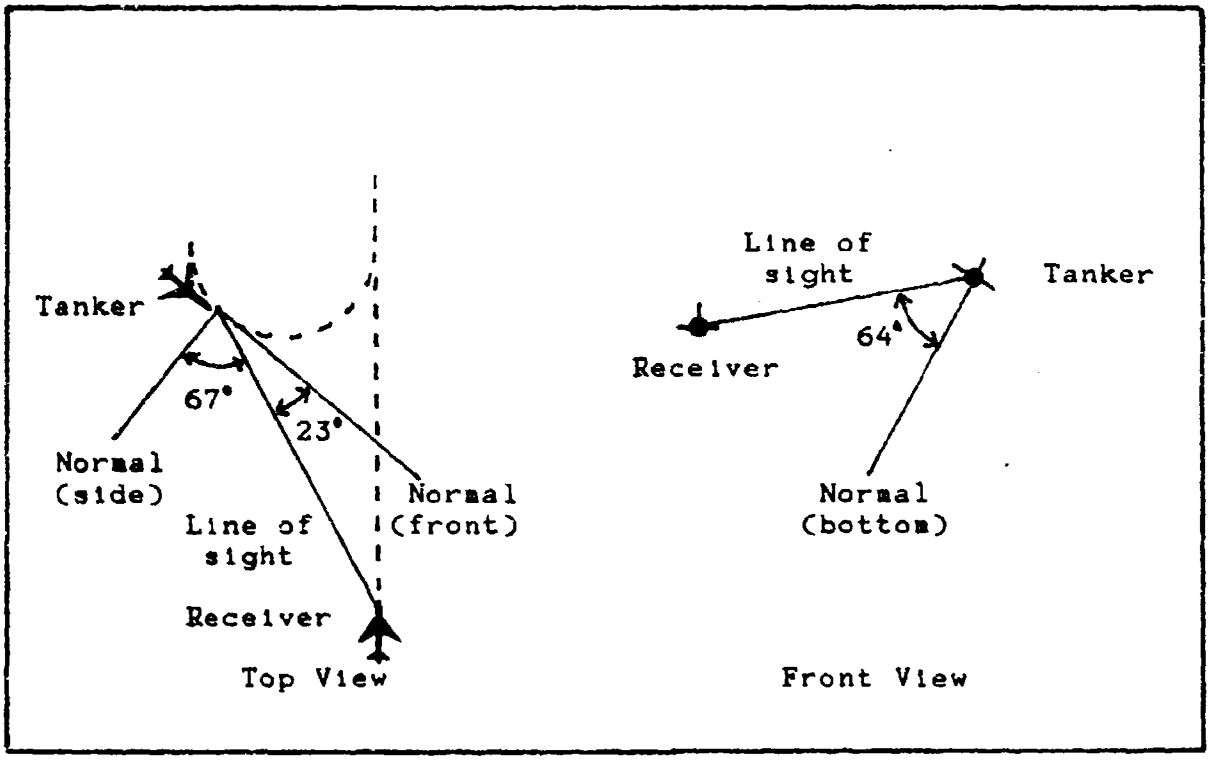


Figure 5. Aircraft Relative Position, Point Parallel Rendezvous

## ENROUTE RENDEZVOUS

The enroute rendezvous procedure differs from the point parallel procedure in that there is no specified tanker orbit in

which the tanker must delay awaiting the receiver. The normal enroute rendezvous with electronic emitters active consists of both aircraft flying to an ARIP within one minute of one another and then along a common track to the ARCP (11:2-15 - 2-16). This section will examine the time in the visual range and the apparent target size for this type of rendezvous.

The procedure, though simple, is well suited for emission out rendezvous because it already relies on timing for its success. The only modification necessary to improve the basic procedure is to make the aircraft arrive at the ARIP at the same time for the same reason mentioned in the point parallel procedure.

Figure 6 shows the relationship of the two aircraft during the rendezvous.

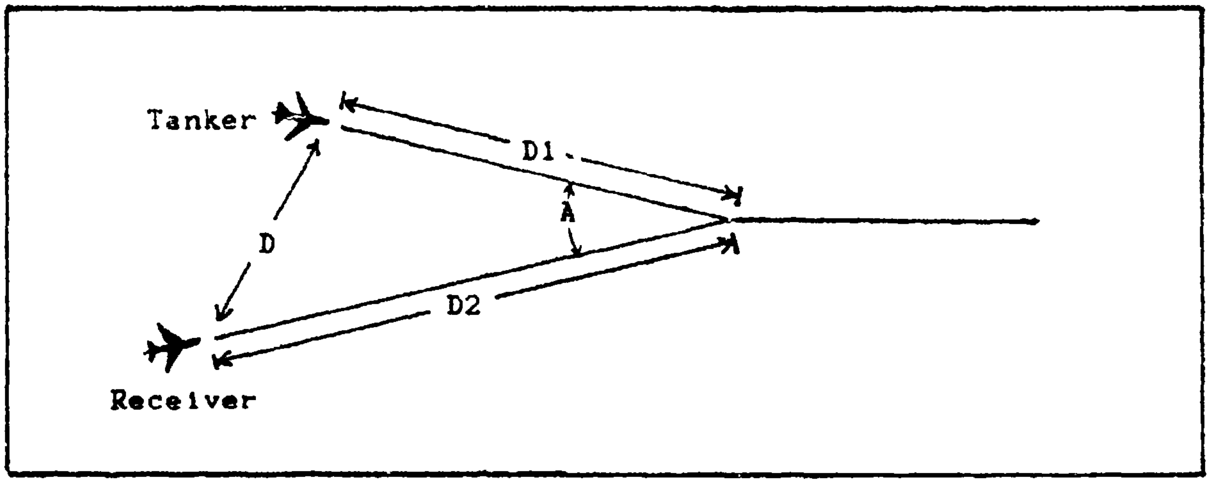


Figure 6. Enroute Rendezvous

The enroute rendezvous can be planned so that the aircraft arrive at the ARIP at any angle. Angles approaching 90 degrees and beyond, however, will affect the aircraft ability to line up on the ARIP - ARCP track after crossing the ARIP because of the large turns necessary after crossing the ARIP. This may negatively affect the rendezvous.

The relative angle between the aircraft will affect the length of time they are within visual range prior to the rendezvous point. The best case would be if both aircraft flew the same track to the ARIP, or a 0 degree relative angle; the

worst would be head-on, or 180 degrees. This example shows two aircraft arriving at the ARIP at a 30 degree relative angle.

The equation which determines the distance, D, between the two aircraft is

D = SQR [ (D1^2) + (D2^2) + 2 x D1 x D2 x Cos A ] (3:8)

where

D1 = tanker distance to the rendezvous point
D2 = receiver distance to the rendezvous point
A = relative angle between aircraft
^ = symbol indicating exponential.

The equation which determines the distance, D1 or D2, from the tanker or receiver to the ARIP is

D1 (or D2) = S1 (or S2) x T

where

S1 = tanker airspeed
S2 = receiver airspeed
T = time (sec).

The following variables were selected for this examination:

Tanker true airspeed = 400 kts
Receiver true airspeed = 450 kts
Wind = no wind
Relative angle = 30 degrees.

Another iterative program can be used to solve the equations. Setting D equal to 10 NM and solving for time, the solution is 159 seconds. This means that the tanker and receiver should be within 10 NM of each other for 159 seconds prior to the ARIP. This occurs when the tanker and the receiver are 17.8 NM and 20.0 NM from the ARIP, respectively. With a 100 knot increase in the receiver's airspeed the time changes to 128 seconds. A detailed listing of the program is in Appendix 2.

To give an idea of the effect of the relative angle, consider the extreme cases. At a 0 degree relative angle, i. e., both aircraft on the same track, the time within the visual range is 719 seconds and the distance from the tanker and receiver to the ARIP are 80 NM and 90 NM, respectively. At a 180 degree relative angle, i. e., both aircraft approaching the ARIP from opposite directions, the time within the visual range is 42 seconds and the distance from the tanker and receiver to the ARIP are 4.7 NM and 5.3 NM, respectively.

The visible area of the target aircraft was computed as in the point parallel procedure. In this case the slower aircraft, the tanker, has the larger visible area. This is true because

the tanker presents a more perpendicular aspect to the receiver than vice versa. The relative position of the two aircraft the first time they are within the 10 NM range is shown in Figure 7.

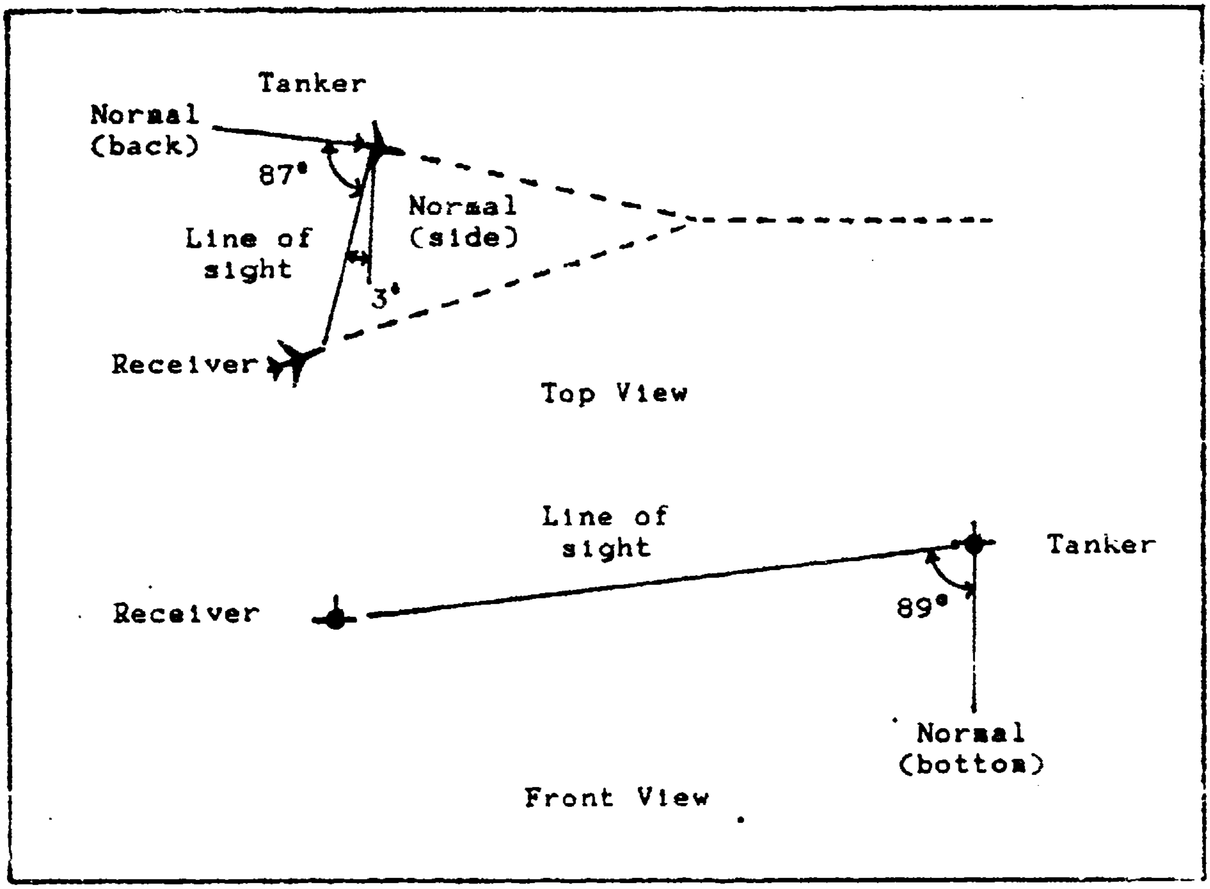


Figure 7. Aircraft Relative Position, Enroute Rendezvous

| | | |
|---|---|---|
| (Back) | $Ax' = Ax \times \cos 87 = 900 \times .05 =$ | 45 |
| (Side) | $Ay' = Ay \times \cos 3 = 4000 \times .99 =$ | 3960 |
| (Bottom) | $Az' = Az \times \cos 89 = 9000 \times .02 =$ | 180 |

Visible area = 3960 + 1/3 (45 + 180) = 4035 sq ft

The initial visible area, then, for an enroute rendezvous with a 30 degree relative angle between aircraft is approximately 4000 sq ft. The next rendezvous is a proposal by the authors to apply the advantages of the previous two rendezvous into a single procedure.

## OFFSET ORBIT RENDEZVOUS

The third type of rendezvous to be examined is a modification of the point parallel rendezvous developed by the authors. It differs from the normal point parallel rendezvous in that the orbit is offset from the ARIP - ARCP track by 30 degrees. Timing remains the primary means of accomplishing the rendezvous. The 180 degree tanker rendezvous turn, like the point parallel rendezvous, increases visible area. The 30 degree intercept to the ARIP - ARCP track, like the enroute rendezvous, increases the time within the visual detection range.

The orbit must be timed so that the tanker crosses the ARCP at the ARCT. A nominal orbit time duration should be selected to optimize the relative position of the aircraft and to provide timing flexibility for the tanker. If the nominal orbit is very small, shortening the leg length to make up time may not be possible. (The orbit can be no shorter than 5 minutes, the time it takes the tanker to complete a 360 degree turn using normal speed and bank angle.) If the leg length is very long, the tanker's rendezvous turn will be complete before the aircraft are within visible detection range and the advantage of the turning tanker's increased visible area will be lost.

The offset orbit rendezvous procedure is shown in Figure 8.

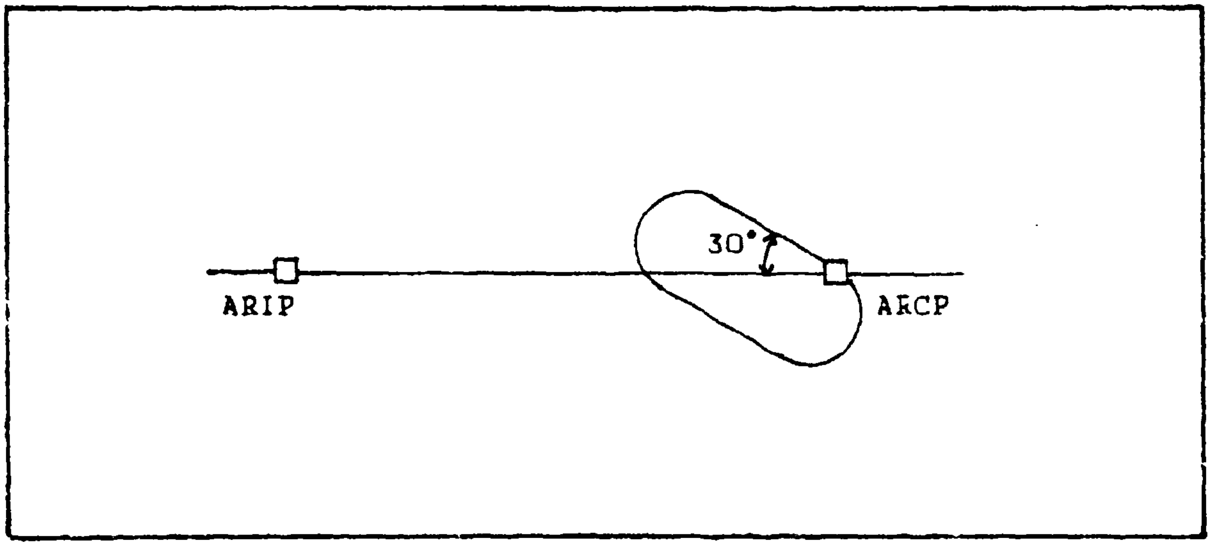


Figure 8. Offset Orbit Rendezvous

For this examination, an 8 minute orbit will be used. The orbit will consist of two 180 degree turns which take 150 seconds each and two legs which take 90 seconds each.

The equation which determines the distance, D, between the two aircraft as the tanker is completing its rendezvous turn is

$$D = SQR \; [ \; (X1-X2)^2 + (Y1-Y2)^2 \; ]$$

where

X1, Y1, X2, and Y2 are as depicted in Figure 9
^ = symbol indicating exponential.

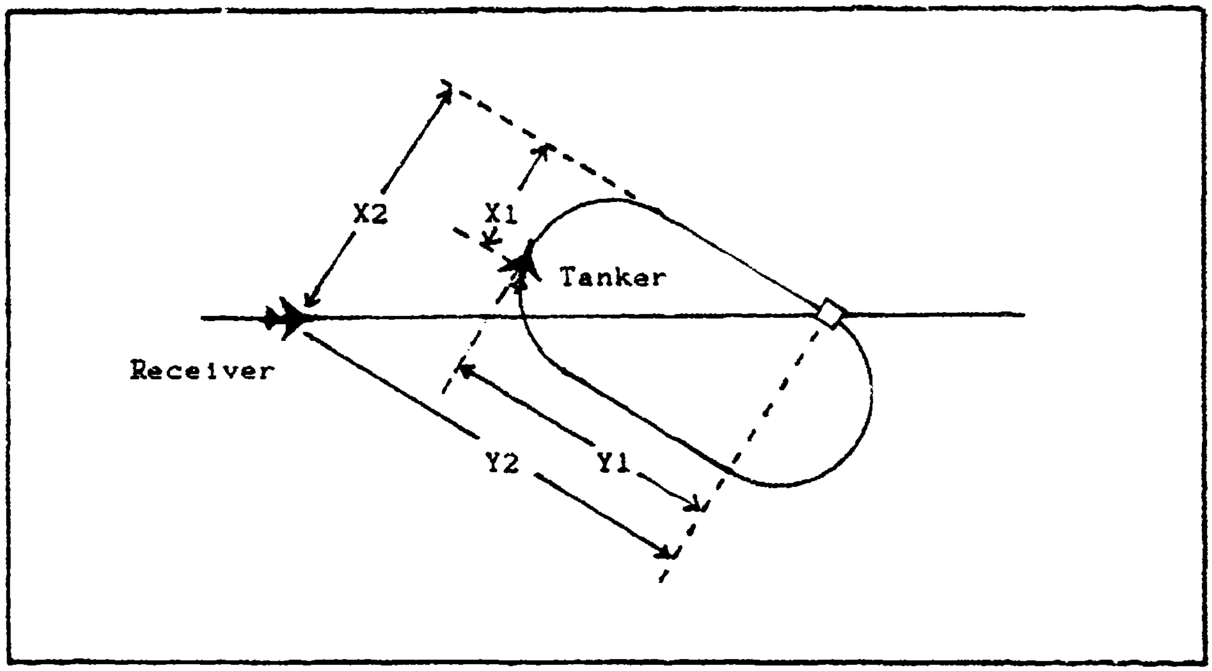


Figure 9. Offset Orbit Rendezvous Turn

The equations for X1, Y1, X2, and Y2 are

$$X1 = OS/2 + OS/2 \times Cos \; (1.2 \times T)$$
$$Y1 = ((400/3600) \times 90) + OS/2 \times Sin \; (1.2 \times T)$$
$$X2 = (450/3600) \times (240 - T) \times Cos \; 30$$
$$Y2 = (450/3600) \times (240 - T) \times Sin \; 30$$

where

OS = offset
T = time from start of tanker turn.

The following variables were selected for this examination:

Tanker true airspeed = 400 kts
Receiver true airspeed = 450 kts
Wind = no wind
Tanker bank angle = 25 degrees
Tanker turn rate = 1.2 degree/second.

Again, the distance D is set equal to 10 NM and the equations solved for the time remaining until the ARCT. Using the same iterative process as in the previous examinations, the time from 10 NM visual detection range until both aircraft cross the ARCP is 206 seconds. If the receiver's airspeed is increased by 100 knots, the time in the visual range drops to 155 seconds. A listing of the program is in Appendix 2.

The visible area of the target aircraft was computed as in the previous examples. In this case the tanker, again, has the larger visible area. The relative position of the two aircraft the first time they are within the 10 NM range is shown in Figure 10.

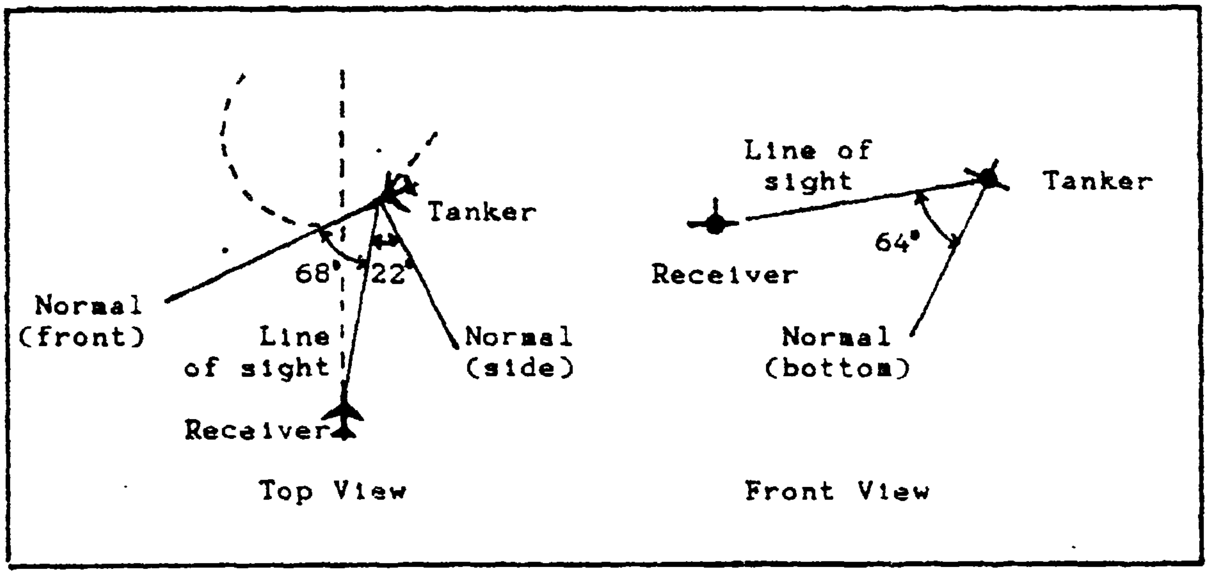


Figure 10. Aircraft Relative Position, Offset Orbit

(Front) $A_x' = A_x \times \cos 68 = 900 \times .37 = 333$
(Side) $A_y' = A_y \times \cos 22 = 4000 \times .92 = 3680$
(Bottom) $A_z' = A_z \times \cos 64 = 9000 \times .44 = 3960$

Visible area = 3960 + 1/3 (333 + 3680) = 5298 sq ft

The initial visible area, then, for the offset orbit rendezvous is approximately 5300 sq ft.

The results of the three examinations of rendezvous types are shown in Table 9.

| Type Rendezvous | Time Within Range (sec) | Visible Area (sq ft) |
|---|---|---|
| Point Parallel | 94 | 4756 |
| Enroute (30 degrees) | 159 | 4035 |
| Offset Orbit (30 degrees) | 206 | 5298 |

Table 9. Rendezvous Investigation Results

This chapter has quantified the factors which affect the probability of a successful rendezvous. Two cautions are made when examining these results. First, only one set of computations was made for each type of rendezvous. While such factors as aircraft size, airspeed, and turn rate were held constant throughout the chapter, other factors, such as orbit size, relative angle approaching the ARIP, and orbit offset angle, were selected somewhat arbitrarily to attempt to balance the advantages of greater time in the visible detection range and greater visible area. Second, the investigation of visible area was done to give general insight into the differences in apparent target size resulting from different rendezvous procedures. The numbers given for visible area in Table 9 should not be used to compute some percentage improvement in probability of one rendezvous over the other. The conclusions which can be drawn are that rendezvous that include a turning tanker offer a greater apparent target size and that the rendezvous that include both aircraft arriving at the rendezvous point from roughly the same direction offer a greater time in the visible detection range. Receiver airspeed changes of 100 knots show a noticeable

reduction in the time in the visible detection range. Airspeed changes of even greater than 100 knots are possible and could have a serious impact on rendezvous success.

The final chapter will give the authors' conclusions on the feasibility of emission out rendezvous. It will discuss the capabilities and limitations of the factors affecting the rendezvous, the suitability of current rendezvous procedures, and recommend areas for further investigation.

## Chapter Six

# CONCLUSIONS

Emission controlled (EMCON) aerial refueling may be required due to enemy communications interference. Additionally, EMCON refueling may be tactically desirable to achieve surprise and/or avoid detection near the battle area by sophisticated enemy early warning equipment (15:1-3).

The Air Force is beginning to recognize the need for developing emission out air refueling procedures. Technical Order (T. O.) 1-1C-1, Basic Flight Crew Air Refueling Manual, defined the term "emission out" for the first time in January, 1987 (10:3). But neither T. O. 1-1C-1 nor any of the aircraft-specific refueling manuals have developed accompanying procedures to accomplish an emission out rendezvous. The conclusions drawn by this paper can be the first step toward the logical development of those procedures. These conclusions on the capabilities and limitations of crews and equipment and the suitability of different rendezvous procedures will provide some answers about emission out rendezvous and recommend areas for further investigation.

Visual detection depends on a variety of factors, primarily the apparent target size, its position within the field of view, and the contrast between the target and its background. In the rendezvous situation these factors relate to the target profile, crew visual search techniques, and visibility restrictions such as clouds or night. The target profile is an important consideration when evaluating rendezvous procedure suitability. Visual search technique is one area which requires further investigation. Studies have shown, for instance, that limiting the search area drastically improves the probability of target detection. Finally, this study has shown that visual detection without limitations to visibility is highly probable. Further investigation, however, is necessary to determine the impact of restricted visibility on rendezvous success.

Maintenance logs of current emission-free inertial navigation systems indicate that they are adequate to perform emission out rendezvous under conditions of good visibility. As visibility

decreases, the effect of navigation system errors becomes more significant. Further investigation here is necessary to determine visibility limits for emission out rendezvous to insure an acceptable probability of success. As future navigation systems become operational, such as the global positioning system, navigation systems will become virtually error free and visibility limits could be reduced.

SAC Bombing and Navigation Competition results indicate that crew and aircraft systems abilities to minimize timing errors are adequate to perform emission out rendezvous. The current lack of emphasis on timing as a rendezvous aid can be remedied by simply changing crew training procedures to add the required emphasis.

Two factors, related to the crew's ability to detect a target aircraft, affect the chance for success of a particular rendezvous procedure. The larger the target profile and the longer the target remains within the visual detection range the greater the probability of rendezvous success. The point parallel rendezvous procedure which requires the tanker to turn presents a larger target profile than one which does not. It also offers the advantage of a planned delay, which offers timing flexibility, and is more suitable for rendezvousing aircraft approaching from opposite directions. The enroute rendezvous procedure, when both aircraft approach the rendezvous point from approximately the same direction, allows a greater time for visual detection. The authors' offset orbit rendezvous procedure combines the advantages of both current procedures. Further work must be done to develop an orbit timing chart for those procedures which use a planned orbit. The comparisons made of the three rendezvous procedures were based on one set of computations. Further study must be done to consider the effects of varying the factors such as aircraft speed, wind, and target size which were held constant in this investigation. Mathematical and flight testing must be done on the offset orbit procedure to determine the best offset and orbit size. Finally, once procedures have been optimized, tanker and receiver crews must be trained to perform those new procedures.

This study has done some basic research on the factors which affect the emission out rendezvous. It has found that none of the factors investigated prohibit its success. It has also compared the current rendezvous procedures and one proposed rendezvous procedure and shown their relative strengths and weaknesses. Recent operational air refueling missions demonstrate the need for proven emission out rendezvous procedures. This study is the first step in the development of those procedures.

Air Force Manual 1-1 lists surprise as one of the basic principles of war. If an enemy is not expecting an attack, he

will not apply his forces against it. Emission out air refueling procedures insure air refueling success without signaling our intentions. The US Marine Corps KC-130 Tactical Manual describes the situation this way:

> Future trends indicate the wide use of meaconing, intrusion, jamming, and interception (MIJI) to interfere with friendly air operations. The capability to conduct aerial refueling operations against this sophisticated threat must be retained, with procedures established whereby tanker and receiver aircraft can rendezvous and conduct a safe, orderly refueling evolution without reliance upon navigation aids and/or radio communications between aircraft (15:1-2 - 1-3).

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## Appendix One

### VISUAL DETECTION AND IDENTIFICATION RESULTS (25:--)

| Target | Detection Range (NM) | Identification Range (NM) | Remarks |
|---|---|---|---|
| (Daylight conditions) | | | |
| KC-10 | 9 | 5 | |
| " | 9 | 6 | |
| " | 10 | 3 | |
| " | 11 | 6 | |
| KC-135 | 7 | 3 | |
| " | 8 | 5 | |
| " | 9 | 3 | Note 3 |
| " | 11 | 10 | |
| " | 14 | 8 | |
| " | 15 | 10 | |
| " | 15 | 12 | |
| " | 18 | 6 | |
| " | 20 | 6 | |
| " | 20 | 8 | |
| B-52 | 6 | 6 | |
| " | 26 | 26 | |
| A-10 | 5 | 5 | |
| (Night conditions) | | | |
| KC-135 | 5 | 5 | Clouds |
| " | 25 | 0.5 | |
| " | 33 | 0.5 | Note 4 |

Note 1: Range measurements were made with air-to-air TACAN.
2: Observations were made by crews from C-5, F-16, and KC-10 aircraft. Target identifications were determined by subjective evaluation of the crew.
3: This crew saw another aircraft which could have been mistaken for the target.
4: Night detection is generally accomplished at great ranges under normal conditions because aircraft lighting is used. This provides a very high contrast between target and background. Elimination of lighting would greatly reduce contrast and hence the detection range.

## Appendix Two

### RENDEZVOUS COMPUTATIONS

1. Computations used for investigation of point parallel rendezvous.

   a. See Figure 4, page 21, for diagram of point parallel rendezvous.

   b. Find the turn range (TR) and offset (OS).

Given: Tanker TAS = 400 kts
Tanker bank angle = 25 degrees
Rcvr TAS = 450 kts

Solution:

From AFM 51-37: OS = turn diameter = <u>10 NM</u>

From AFM 51-37: turn rate = 1.2 deg/sec
Time for 180 deg turn = 180/1.2 = 150 sec
Y1 = 450 kts / 3600sec/hr * 150 sec = 18.75 NM
TR = SQR [ 10^2 + 18.75^2 ] = <u>21.25 NM</u>

   c. Listing of program used to compute time in visual range.

```
100  REM :COMPUTE PP TIME
110  REM :TANK TAS = 400
120  REM :TANK BANK = 25 DEG
130  REM :TANK TURN RATE = 1.2
140  REM :OFFSET = 10 NM
150  REM :RADIUS (R) = 5 NM
160  REM :WIND = 0
170 R = 5
180  INPUT "ENTER RCVR TAS: ";S1
190 S1 = S1 / 3600
200  FOR T = 0 TO 150
210 A = 1.2 * T / 57.2957795
220 S =  SIN (A)
230 C =  COS (A)
240 X = R + R * C
250 Y1 = S1 * (150 - T)
260 Y2 = R * S
270 Y = Y1 - Y2
280 D =  SQR ((X ^ 2) + (Y ^ 2))
290  IF 10 > D THEN  GOTO 310
300  NEXT T
310  PRINT "TIME = ";150 - T
```

```
320  PRINT "ANGLE = ";A * 57.2957795
330  PRINT "DISTANCE = ";D
340  END
```

2. Computations used for investigation of enroute rendezvous.

a. See Figure 6, page 24, for diagram of enroute rendezvous.

b. Listing of program used to compute time in visual range.

```
100  REM :COMPUTE ENRTE TIME
110  REM :TANKER TAS = 400
120  INPUT "ANGLE = ";A
130 S1 = 400 / 3600
140  INPUT "ENTER RCVR TAS: ";S2
150 S2 = S2 / 3600
160 A = A / 57.2957795
170  FOR T = 1 TO 1000
180 D1 = S1 * T
190 D2 = S2 * T
200 D =  SQR ((D1 ^ 2) + (D2 ^ 2) - (2 * D1 * D2 *  COS (A)))
210  IF D > 10 THEN  GOTO 230

220  NEXT T
230  PRINT "TIME = ";T - 1
240  PRINT "DIST = ";D
250  PRINT "D1 = ";D1
260  PRINT "D2 = ";D2
270  END
```

3. Computations used for investigation of offset orbit rendezvous.

a. See Figure 8, page 27, and Figure 9, page 28, for diagram of offset orbit rendezvous.

b. Listing of program used to compute time in visual range.

```
100  REM :COMPUTE OFFSET TIME
110  REM :TANKER TAS = 400
120  REM :TANK BANK = 25 DEG
130  REM :TANK TURN RATE = 1.2
140  REM :OFFSET = 10 NM
150  REM :RADIUS (R) = 5 NM
160  REM :WIND = 0
170 R = 5
180 S1 = 400 / 3600
190  INPUT "ENTER RCVR TAS: ";S2
200 S2 = S2 / 3600
210  FOR T = 0 TO 150
```

```
220 A = 1.2 * T / 57.2957795
230 S =  SIN (A)
240 C =  COS (A)
250 X1 = R + R * C
260 Y1 = (S1 * 90) + (R * S)
270 X2 = (S2) * (240 - T) *  SIN (30 / 57.2957795)
280 Y2 = (S2) * (240 - T) *  COS (30 / 57.2957795)
290 D =  SQR ((X1 - X2) ^ 2 + (Y1 - Y2) ^ 2)
300  IF 10 > D THEN  GOTO 320
310  NEXT T
320  PRINT "TIME = ";150 - T + 90
330  PRINT "ANGLE = ";A * 57.2957795
340  PRINT "DISTANCE = ";D
350  END
```